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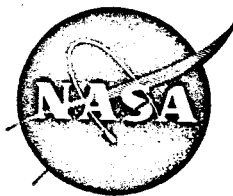
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DEVELOPMENT OF A
SEALED LEAD-ACID BATTERY
FOR USE IN SPACE

BY
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FINAL REPORT
FEBRUARY 26, 1966

PREPARED FOR
GODDARD SPACE FLIGHT CENTER
CONTRACT NAS 5-2872
C&D BATTERIES
DIVISION OF ELTRA CORPORATION
CONSHOHOCKEN, PA.

**C&D BATTERIES
DIVISION OF ELTRA CORPORATION**

Contract #NAS-5-2872

February 26, 1966

FINAL REPORT

TITLE: Development of a Sealed Lead-Acid Battery for Use in Space

SCOPE OF WORK: The development of a hermetically sealed non-magnetic lead-calcium cell for space craft application. The effort was divided into two phases:

Phase I may be defined as "Proof of Principle" while


Phase II is the development of a space craft battery.


ABSTRACT: A sealed lead-acid battery with lead-calcium alloy for the grid metal has been developed. It has the following advantages:

1. Non-Magnetic
2. Capable of high current discharge
3. Shelf storage of 6 months with little loss in capacity
4. No heat degradable material in the interior of the battery

It has the following disadvantages:

1. Liquid electrolyte in the battery
2. Battery does not complete recharge in 90 minute orbit
or at low temperatures.


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Director of Project


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PHASE I

This section of the report marks the completion of Phase I of the subject contract. It establishes the probable limitations in power output of lead-acid batteries when used in a test cycle featuring 30 minutes discharge and 60 minutes charge.

6.9 watt hours per pound was obtained using a test cell containing 0.090 inch thick plates. The test was continued for 250 cycles at 77° F. without deterioration of capacity or apparent change in the cell.

6.2 watt hours per pound was obtained at 32° F. on a similar cell during a series of capacity test discharges, but it was found that charge could not be completed in 60 minutes, so that the power actually available on a 90 minute cycle would be somewhat less. The actual available capacity has not yet been determined.

Data is available to indicate that the use of 0.040 inch plates will deliver 10 watt hours per pound at 77° F. The effect of plate thickness on the charge process at 32° F. indicates that an output of 5 watt hours per pound or more will be obtained.

Preliminary tests indicate that gas evolution on open circuit is unmeasurable and amounts to less than 30×10^{-6} cc/hr. /AH capacity.

Remaining to be studied in Phase II of the project are the following:

1. Useable capacity during cycle tests at 32° F.
2. Gas evolution during charge and discharge

3. Life tests
4. Methods of absorbing gas which may be formed
5. Reliability of sealing methods
6. Design and pilot models of thin plate batteries
7. Test of pilot model cells

EXPERIMENTAL

Power Output: Table 1 shows the power output for cells which have been fully charged. The first column shows the experimental results using cells which were available for test, while the second column shows the calculated results assuming that cells of optimum design were available.

Preliminary tests were also run on cells containing positive plates 0.266 inches thick. These are designed for long life at a low discharge rate and gave the expected low capacity at the 30 minute discharge rate. The cells shown in Table 2 had plates 0.090 inches thick and gave a reasonably good performance. The optimum design is based on plates 0.040 inches thick. Since the test data from the first two constructions fit our design curves, we feel confident that the same design curves can be used to predict the output of the 0.040 inch plates.

The first tests were on 0.090 inch thick positive which were defective. The plates had received other tests previously and had been allowed to stand idle for a long time. They did not give the expected capacity and a new set of batteries was prepared. The data in the table are for this new

set of batteries.

TABLE 1 POWER OUTPUT
FULLY CHARGED CELLS

	<u>Experimental</u>	<u>Calculated</u>
Plate Thickness	0.090	0.040
Nominal Capacity 8 hr. rate @ 77° F.	17 WH/lb.	15 WH/lb.
Test Capacity 30 min. rate @ 77° F.	6.9 WH/lb.	10.5 WH/lb.
Test Capacity 30 min. rate @ 32° F.	6.2 WH/lb.	9.4 WH/lb.

Charge Time:

The charge-discharge characteristics during the cycle test are show in Fig. 1-4, where the charge time was prolonged to 2 hours to show details of the charge characteristics.

Fig. 1 shows the current and voltage during cycle at 77° F. Here charge appears substantially complete in 60 minutes at 77° F. This was checked by putting the test cell on automatic life cycle for 2 weeks using the 60 minute charge and 30 minute discharge. There was no deterioration of capacity, and we therefore, feel that the charge is substantially complete in 60 minutes.

Fig. 2 shows similar data during a test at 32° F. Here it is obvious that charge is not complete in 60 minutes and that the capacity

available during a cycle life test will be controlled by the amount of charge the battery will accept. This has not yet been verified by a life cycle test and such a test is clearly necessary in order to learn the power output available. This is particularly important since we do not yet know how this charge acceptance varies with battery life and the maximum capacity at which battery operation will stabilize.

Fig. 3 shows the charge characteristics in a different fashion. The standard rule for charging a battery is that it will accept at least 1 ampere of current for every ampere hour equivalent to the lead sulfate in the battery plate. The dotted line on the chart shows the limitation of this rule, while the experimental data shows this rule still applies. It shows clearly that data can be plotted on what is almost a straight line and that at 60 minutes, charge is substantially 100% at 77° F., while at 32° F. it is only 86% complete.

Attempts to shorten the charge period by using a higher voltage were made and are shown in Fig. 4, 5 and 6. Here it is clear that after 60 minutes of charge the battery is still accepting 0.4 to 0.6 amperes at each voltage and obviously the battery is not fully charged because the charge current keeps decreasing.

Optimum Design:

For satellite application, we have mentioned that a 0.040 thick plate appears to be about optimum. Thick plates give their maximum

output only when the discharge time is long. Extremely thin plates are difficult to make and have a relatively short life. We feel that 0.040 inch plates strike about the best practical performance within the life requirements. The effect of plate thickness is shown best in Fig. 7 prepared from data by Harner and Chub (Reference 1). We have extended this work into the range of thinner plates (Reference 2) and have obtained analogous data on negative plate and electrolyte volume. (Proprietary information.)

It is on this basis that we feel safe in estimating that 10 watt hours per pound can be obtained during a 30 minute discharge.

Low Temperature Capacity:

Capacity data at 32° F. is available in Reference #2 and Fig. 8 and is the basis for our estimate of battery output where the capacity is limited by the amount of active material, not by charge acceptance.

Low Temperature Charge:

The effect of temperature on the charge acceptance has been investigated (Reference 3). The data from this reference are plotted in Fig. 9 showing how it compares with data obtained in this work. In view of the difference in test cells and test methods, there is no doubt that the present work comes close enough to the earlier work to justify extrapolating the line to lower temperatures and concluding that at tempera-

tures of less than 32° F. , the charge time will probably exceed that available on a 90 minute orbit cycle. Whether this is a fatal objection depends on getting more data.

Gas Evolution Tests:

Because of the small amount of gas anticipated, we have run tests using a set of 500 ampere hour batteries and measured the pressure rise with an oil manometer. After two weeks there was no detectable gas evolved and only the normal day-to-day variations in pressure due to changes of temperature and barometric pressure.

One cell was flushed with hydrogen to give a 70 mm added pressure. This cell maintained its added pressure and shows that we were not measuring a leaky cell or hydrogen diffusion, but that the actual gas evolution was actually close to zero.

On the basis of this test, we feel that hydrogen evolution amounts to not more than 30×10^{-6} cc per hour per ampere hour of rated capacity when the cell is on open circuit.

In view of the results obtained in Phase I, the following program was started:

1. Prepare batteries of a proposed design with 0.090 plates and put them on life test at 77° F.
2. Measure gas evolution rate during charge and discharge to supplement the open circuit test already available.

3. If the gas evolution is sufficient to require means of absorbing it, study those methods which appear practical.
4. Design and test sealing procedures.
5. Design of grid molds and accessory parts for cell is proposed design data with hand built grids and jars looks favorable.

PHASE II

The Phase I work indicated that the lead calcium battery would be adaptable to the design parameters required for a space craft battery. No complete specifications were available from NASA on this battery except that it be about 5 ampere hours, attain a maximum watt hour/pound ratio and be capable of being charged in 60 minutes.

The cells which had been under test for Phase I were of a design used for float service and not for a cycle service as would be required for space craft.

The lead calcium battery is normally kept on "float" on a charge line whose voltage is somewhat higher than the open circuit potential of the cell, but not high enough to cause actual gassing at the electrodes. For a true "float" the cells must be in balance, that is the capacity of the negative plates should very closely match the capacity of the positive plates. Also, the cells must be fully charged. The efficiency of charging is slightly different for positive and negative plates and differs with different charging rates and other conditions. (4)

The design of a sealed cell for cycle service and little or no "float" operation, called for a new set of parameters for such a battery. Except for the fact that the battery would have lead-calcium grids, it was obvious that the resemblance to a regular lead-calcium cell for float service would be remote for the following reasons:

1. High discharge rates - The cell must be capable of discharge for thirty minutes at rates from C/5 to C to an end voltage of 1.75 volts.
2. High Rate Charge - The cell must be capable of being recharged in 60 minutes with a minimum of gassing.

These requirements in themselves are rather stringent and call for a thin plate battery, and some means of absorbing the oxygen which will be given off during discharge and possibly during charge.

The use of thin plates in themselves presented an appreciable problem in casting. The optimum power performance as shown by Phase I would be given by grids of .040" thickness. Pressure casting would have been necessary for a grid this thin in lead-calcium alloy. Such a casting process however does not produce grids that will withstand corrosion, so the use of grids at .040" thickness was not considered.

It was decided from past experience that a grid of .090" thickness would be about the minimum thickness grid which could be cast in lead calcium with available equipment and have an acceptable life under cycling conditions.

The use of lead-antimony for the grid alloy would allow the casting of the .040" grids, but the high self discharge of the lead-antimony battery and its gassing rate on open circuit as well as charge, ruled out the use of lead-antimony.

The control of gassing was an entirely separate problem and initially

was felt to be the most severe problem.

There were several approaches which were considered for controlling the gassing:

1. Close control of charging voltage to limit hydrogen evolution from the negative plate.
2. Negative active material exposed above the acid level for oxygen recombination.
3. Auxiliary electrodes for recombination of oxygen and hydrogen in the cell.
4. Zener diodes shunted across the cells for voltage control of individual cells.
5. Encapsulate cell in such a manner that it would be capable of operation at high pressures.

As open circuit gassing is almost non-existent in the lead-calcium cell, oxygen evolution on discharge with some on charge and hydrogen evolution on charge would be the main problem. The easiest and most practical manner to control hydrogen gassing is by keeping the cell voltage below 2.35 volts. The use of excess negative material exposed in the gas space appeared the most practical for control of oxygen.

The use of auxiliary electrodes was not considered initially as no such system was readily available and it would require at least six sets of electrodes in a cell for auxiliary electrodes to always be in the gas space in the cell.

The use of Zener diodes for individual cell voltage control was quite desirable but no Zener diodes were found that would carry currents of .5 amperes or better with a sharp cut-off voltage at 2.28 to 2.30 volts.

The first prototype cell was built up with .090" positive and negative plates which were available in a larger size and cut down. The cell was an eleven plate cell with 5 positive plates and 6 negative plates. The cell data is given below:

Positive Plate - 1.5" x 3.25" x .090"

Negative Plate - 1.875" x 3.75" x .090"

Separators - Rubber - .055" thickness

Slyver Glass Mat used on positive plates.

Wt. negative active material as sponge lead - 235 gms.

Wt. positive active material as lead dioxides - 102 gms.

Sp. Gr. of Electrolyte - 1.250

Cell Capacity - 7.5 AH at 6 hr. rate

3.9 AH at 1/2 hr. rate

The cell was put into a battery jar, formed, equalized and acid level adjusted to leave exposed negative active material. The entire jar was encapsulated in epoxy resin with a vent for connection of a mercury manometer. The lead posts were also sealed with the epoxy.

The cell was put on test with a manometer attached and cycled on a 90 minute cycle and the following conditions:

Discharge - 3.8 amps. for 30 minutes

Charge - (Constant Current)

2.6 amps. for 25 minutes

1.6 amps. for 25 minutes

.6 amps. for 10 minutes

On this duty cycle, the cell was not brought back to a complete state of charge each cycle, and would require a boost charge periodically. The need for this was indicated by cell voltages dropping to less than 1.75 volts at the end of the discharge period.

A mercury manometer was connected to the cell during these preliminary cycles to determine gassing characteristics. A negligible pressure buildup was noted on discharge but on charge, pressure built up slowly at a cell voltage of 2.25 volts, much more rapidly at 2.30 volts and quite rapidly at 2.35 volts. Above 2.35 volts the cell was obviously gassing freely. This indicated that charging in a fully sealed condition would be limited to cell voltages of 2.25 to 2.30 volts per cell maximum.

Cycle testing on this cell with manual control constant current charging to simulate constant potential charging showed that a charge equivalent to 2.22 to 2.26 volts per cell for 60 minutes would not maintain the capacity of the cell for more than 50 cycles before cell voltage dropped below 1.75 on discharge. A manually controlled constant current charge to simulate a 2.28 volt constant potential charge resulted in 175 cycles before a boost charge was necessary.

The following conditions were set up on an automatic circuit for

the 90 minute duty cycle:

Discharge - 4 amps. for 30 min.

Charge - 3.3 amps. for 25 min.

1.2 amps. for 25 min.

.6 amps. for 10 min.

The gas collected during this duty cycle was analyzed for oxygen only and 23.2% oxygen found in a sample collected over a 24 hour period. This indicated that oxygen absorption in the cell was not complete but that some absorption is occurring at about an atmosphere absolute pressure while hydrogen is probably diffusing through the rubber gas bag used to collect the gas.

Capacity measurements were made on this cell at:

Cycle #188 - 3.37 AH at 1/2 hr. rate

Cycle #256 - 3.38 AH at 1/2 hr. rate

Cycle #444 - 3.2 AH at 1/2 hr. rate

Cycle #570 - 4.5 AH at 1/2 hr. rate

The cell was removed from circuit at cycle 682 and the cell left at NASA, Goddard SFC with Paul Donnelly for further testing.

The apparent capacity deterioration observed to cycle #444 was a false indication and was due to the cell not having reached a full state of charge. The cell had been charged through the 60 minute charge cycle and finished at 0.1 amp. for 24 hours. Prior to the capacity at cycle 570, the cell was charged for the 60 minutes and finished at 0.1 amp. for 48 hours. Third electrode readings cannot be taken on this cell, so it was

not known whether it was the positive or negative which was slow in coming to a full state of charge.

After this preliminary work on a single, partially sealed cell, grids were designed and molds were cut to cast the positive and negative grids. A 5 cell mono-block container of styrene was available so the grid and element were designed to utilize these containers.

Fig. 10 (dwg. #3137) shows the grids.

Fig. 11 shows pasted negative and positive plates before assembly and formation.

Fig. 12 shows the relative position of a positive plate to the negative plate in an element. The black lines indicate the acid level in any position.

Fig. 13 shows the post and strap, separators, slyver glass and moss shield used in the cell.

A five cell battery was built in the mono-block construction. An epoxy top seal was made with provision for completely sealing the vents to the cells. Encapsulation of the entire unit was not completed at this time but was to be done when the cells were sealed.

The epoxy top seal involved imbedding the 1/8" lead wire posts in an epoxy overlay on the cell cover. The cell cover was a 1/2" piece of PVC with the posts coming through it and this cover cemented to the styrene jar. This type of seal has been in successful use by this company for a number of years for "dead top" construction.

The initial capacity of the cell was 3.0 AH at the 1/2 hour rate to 1.75 final voltage.

The battery was put on cycle at the following conditions:

Discharge: 3 amps. for 30 min.

Charge: 1.5 amps. for 60 min.

The battery was cycled for 145 cycles at room temperature and vented with no apparent loss in capacity. The charge voltages however exceeded 2.5 volts per cell with appreciable gassing.

The recharge conditions were changed to a modified constant potential charge and the depth of discharge increased.

Discharge: 4 amps. for 30 min.

Charge: CC 3 amps. for 30 min.

Constant Potential for 30 min. at a bus voltage of 11.8 volts (2.36 volts/cell).

The 5 cell battery was on the above duty cycle an additional 128 cycles in a vented condition. Recharge was good with no apparent capacity loss as battery voltage was holding at 9.0 to 9.2 volts (1.80 to 1.84 volts/cell) at the end of discharge. At the end of the charge period however, non-uniformity in cell voltages was noted with one or two cells going to 2.55 volts and the remainder holding at 2.30 volts/cell. Cycling was discontinued at 273 total cycles, the battery was completely encapsulated with a filled epoxy resin, two cells were completely sealed and three were sealed with pressure gauges.

The duty cycle previously used was tried with the cells sealed. One cell went to a cell voltage of 2.55 volts and built up 8 pounds of pressure in one recharge cycle. The duty cycle was again modified to:

Discharge: 4 amps. for 30 minutes

Charge: CC - 2.6 amps. for 33 minutes

CP - 27 minutes at 11.8 volts (2.36 volts/cell)

Pressure buildup continued in the cells but not as much as the previous cycle with a pressure of 19 psi in one cell. The battery after recharge was put on a boost recharge of .030 amps. for 72 hours. Previous cells at this rate had held at 2.28 to 2.30 volts, but this five cell unit went to 2.45 to 2.55 volts per cell and gassed at this rate with one cell building to 52 psi, one to 48 psi and one to 20 psi. Rupture of the internal walls of the mono-block container finally occurred as indicated by equalization of the cell pressures.

This unplanned pressure test did reveal that the mono-block five cell unit would not be satisfactory, a stronger jar material would be called for and some modification of the epoxy top seal was needed. It was imperative that cell voltages be always kept below 2.35 volts to keep gassing to a minimum. The use of individual cells with encapsulation was planned for all future cells.

Fig. 14 shows an individual cell with top seal before encapsulation.

Fig. 15 shows an individual cell after encapsulation.

This construction was used for all the remaining cells for testing.

Several groups of 5 cells were built for cycle testing and cycled at various discharge depths. The cells were sealed with a gas collection device and the volume of evolved gas measured.

Fig. 16 is the differential voltage recording of one cell in a battery of five cells during one cycle at C/5 discharge.

Fig. 17 is the differential voltage recording of one cell in a battery of five cells during one cycle at C/2 discharge.

Fig. 18 is the differential voltage recording of one cell in a battery of five cells during one cycle at C/2 discharge where the cell voltage was dropping well below 1.60 volts.

Fig. 19 is the differential voltage recording of one cell in a battery of five cells during one cycle at C/5 discharge.

Fig. 20 is the differential voltage recording of the same cell 40 cycles later at C/5.

A set of four of these cells was sent to NASA, Goodard SFC for preliminary testing. The cells were sealed but not encapsulated. These cells were later sent to USNAD, Crane, Ind. for test. The test revealed that the cells would not accept sufficient charge in the 60 minute charge period, particularly at 0°C. to maintain capacity. (5)

This result was not particularly surprising as it was known from initial testing that periodic boost charges would be a necessity. These cells however did not properly respond to an extended boost charge at 2.25 volts per cell.

An internal inspection of the cells revealed nothing so the elements were charged in a baker of acid at high current rates and discharged at high current rates. After three such cycles, and a recharge at constant current to a cell voltage of 2.7 volts, the cells were found to be at the original capacity. This capacity recovery indicated that no permanent loss of capacity or element damage had occurred.

The gassing characteristics of the element on the initial high voltage recharge was abnormal in that the positives very soon gassed but the negatives were slow to gas. As the capacity recovered the negative plates gassed vigorously shortly after the positive plates started to gas.

This charge acceptance problem was quite disturbing because it does not occur in lead calcium cells of normal design. Lead calcium cells for stationary use do not show charge acceptance problems even at a low charge voltage. These stationary cells are designed with a close balance of positive and negative active material.

These sealed cells are designed with a large excess of negative active material for control of oxygen from the positive during charge and discharge. This lack of balance between the positive and negative active material in the sealed cells must be the cause of the charge acceptance problem. The following is probably occurring during the charging cycle.

The cell on charge at 2.25 volts has a polarization of .160 volts above open circuit voltage. The positive and negative both accept charge initially at a good rate until the positive becomes charged and polarized

to .100 to .125 volts. At this point with constant potential charging, the negative will only be polarized to .035 to .060 volts and will be quite slow to finish charge. In addition, the positive will be evolving some oxygen at this point, which will be reacted by the exposed negative plate and discharging this exposed edge during its charge cycle. With this charge mechanism and a 60 minute charge period, the negative plate will always be operating in a partially discharged condition. This could also contribute to a negative plate which would be difficult to recharge completely.

A redesign was considered and two cells built, one with a normal design balance of positive to negative active material and the other cell with an excess of positive active material, and neither cell with exposed negative in the gas space.

After formation and conditioning cycles, these cells were sealed and pressure gages attached. The cells were manually run on a 90 minute orbit at C/2 discharge and charged at 1/2 discharge rate to 2.25 volts and 2.25 volt C. P. charge for the remainder of the 60 minute charge period. The normal design cell developed eight pounds pressure in two cycles while the excess positive cell developed twenty pounds pressure in two cycles. The sealed cells with excess negative do not build pressure like this on an identical duty cycle.

The cell with excess positive material also built up pressure during discharge indicating that oxygen was evolved during discharge. As the sealed cells have not shown pressure buildup on discharge, the exposed

negative and excess negative material is reacting with the oxygen evolved.

At first, it was suspected that the deterioration of capacity had occurred as in the thin plate lead calcium submarine cells. This was not that kind of trouble as the submarine cell troubles were positive plate troubles while these sealed cells have negative plate recharge problems.

The negative plates are made of a proprietary lead oxide-sulfuric acid-water mix with expanders. Further work was not done on the negative active material.

CONCLUSIONS AND RECOMMENDATIONS

These sealed lead-calcium cells have shown what was expected except in the charge acceptance of the negative plate. The battery is non-magnetic, capable of high current discharges, can be "floated" at a very low current and has a low self discharge rate.

The power/weight ratio can be improved by selected of a stronger plastic for the jar. This was not done for these cells because of the great expense of jar molds.

The elements can also be easily braced internally to withstand shock requirements.

The free electrolyte in the cell may be troublesome in gravity free flight but as it is part of the electrochemical system, cannot be reduced. Gelled electrolytes have not been reported to be highly successful, and were not investigated.

The design parameters normally used for lead-calcium batteries establish a rather close balance between positive and negative active material, with no recharge problems.

The deviation from these design parameters for this sealed lead-calcium battery with the use of excess negative material and exposed negative in the cell has caused a charge acceptance problem in the negative plates. The need for a periodic boost charge was initially anticipated as it was doubtful that the cell could be brought to a full state of charge in one hour under non-gassing conditions.

The slow rate of recovery of the negatives on extended boost charge was not anticipated. This charge acceptance problem was very serious at 0°C. but less severe as temperature was elevated.

The capability of this lead-calcium battery has not been explored at higher operating temperatures or on longer orbits. Further testing at temperatures to 170° F. should be planned, as other than acceleration of grid corrosion, the higher temperatures should not damage any of the components of the cell.

The operational characteristics of these batteries should be investigated on the 3 hour orbit and longer orbits and on open circuit to determine capability of extended flight then use, without necessity for boost charge or recharge and no necessity for an activation system.

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APPENDIX #1

Electrochemical System Lead Acid

Manufacturer C&D Batteries, Div. of ELTRA Corp.

Date of Manufacture December 1965

AH Capacity: Rated 5 A. H. @ 30 minute rate

* Actual 5 A. H. @ 30 minute rate to 1.5
volts/cell

Cell Dimensions (cm) L 10 CM W 5.6 CM

HGT including terminals 165 cm.

HGT not including terminals 152 cm.

Cell Weight (gm) Dry 760 gms.

Wet 930 gms.

Encapsulated 1640 gms.

Type of Seal Epoxy

Inner Case Material Styrene with PVC Cover

Retaining Case Aluminum Case with Epoxy

Bursting Pressure of Case (psig) 100 psi

Cell Volts (OCV) 2.09

Weight of Case & Terminals (gm) 145

* Watt Hours per Pound 5 @ 30 min. to 1.50 volts

* Indicate rate of discharge, temperature and method of charging before test discharge if applicable.

Plates

(a) Positive Plate

No. of Plates/Cell 3

Dimensions (cm) L 8.25 cm W 5.7 cm T 0.229 cm

Weight (gm) Dry 56 gms

Grid

Material Lead-Calcium 0.025% Ca

Dimensions (cm) L 8.25 W 5.71 T 0.229

Weight (gm) 23

Structure Cast

Weight of Active Material (gm) 30.7

Additives None

(b) Negative Plate

No. of Plates/Cell 4

Dimensions (cm) L 9.55 W 7.01 T 0.229

Weight (gm) Dry 82 gm

Grid

Material Ca Pb 0.025% Ca

Dimensions (cm) L 9.55 W 7.01 T 0.299

Weight (gm) 30

Structure (expanded metal, sheet stock, etc.) Cast

Weight of Active Material (gm) 54.6

Additives Barium Sulfate and Lampblack

Electrolyte

Chemical Description Sulfuric Acid in Water

Per Cent per Weight 33-1/3%

Specific Gravity 1.250

Quantity per Cell (cc) 136

Seal

Basic Materials Dead Top - Epoxy Resin on

PVC Cover and Styrene Jar

Additional Information

Drawing Numbers K-3137

Separators

Positive Electrode

* Material (s) Glass Mat - Slyver Type Glass

Number of Layers of Separators by Type 1

Dimensions (cm)

Type 1 L 17.15 W 5.70 T .0635

Weight (gm)

Type 1 2.1 gms Type 2

Type 3 Type 4

Negative Electrode

* Material(s) Microporous Rubber

Number of Layers of Separators by Type 1

* List materials as follows: Type 1 - Adjacent to electrode
Type 2 - Next material, etc.

Dimensions (cm)

Type 1 L 9.5 W 6.57 T .140

Weight (gm)

Type 1 3.1

FIG. 1

Typical Cycle @ 77°F
2.3 Volt Charge

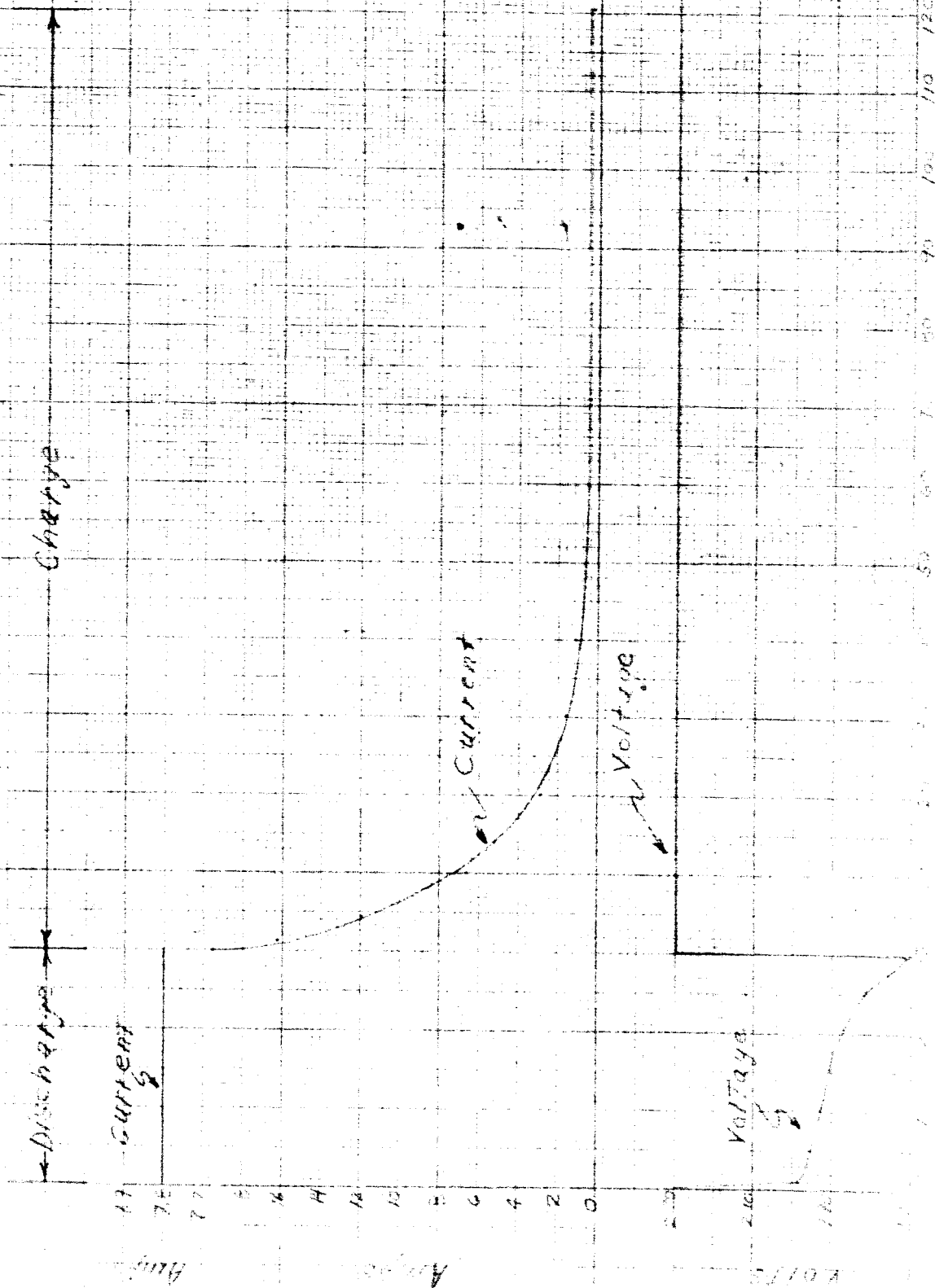


FIG 2

Typical Cycle @ 35°F
2.3 Volt Charge

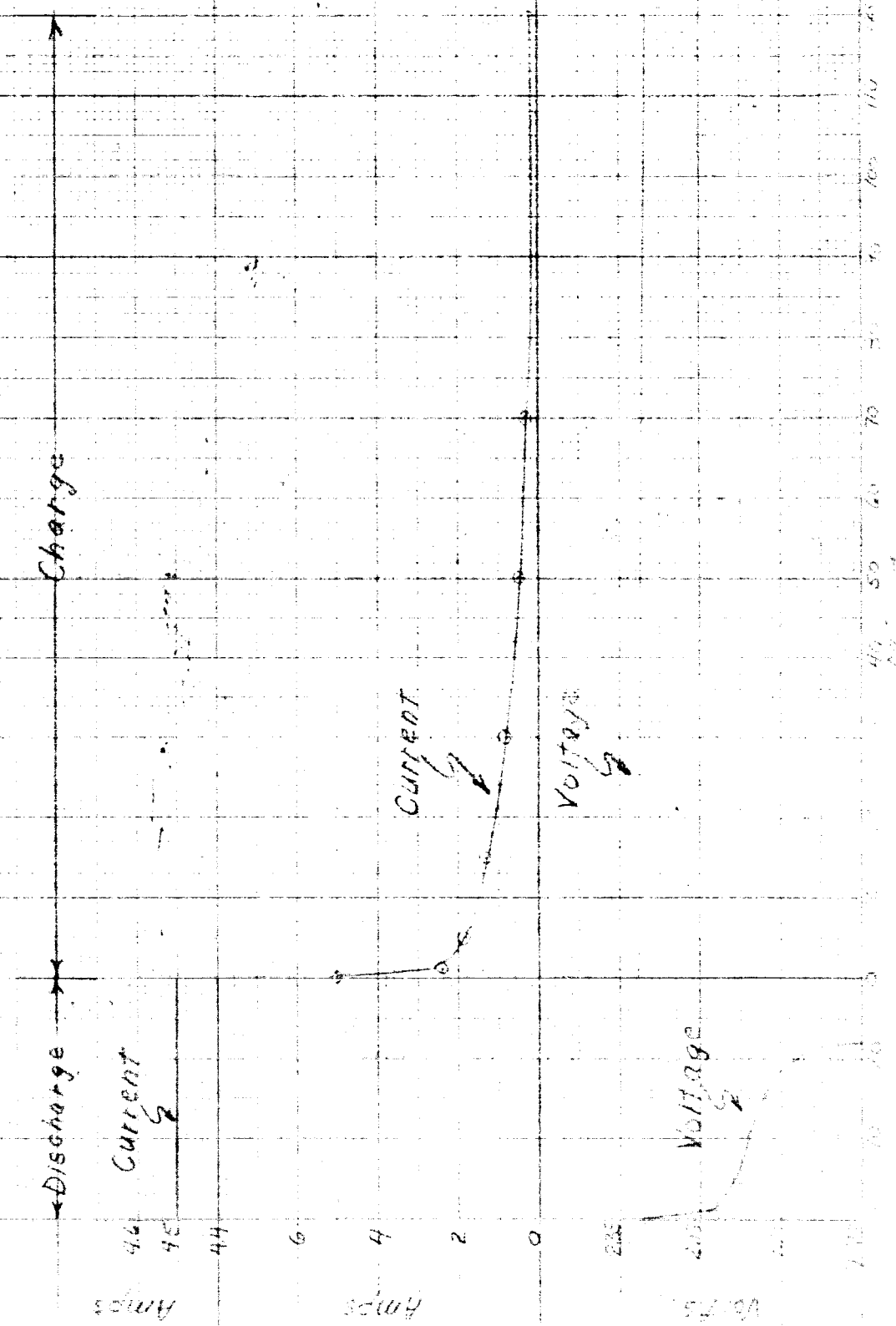


FIG 3

CHARGE-RECHARGE TEST

Amperes Charge/ A.H. Discharge

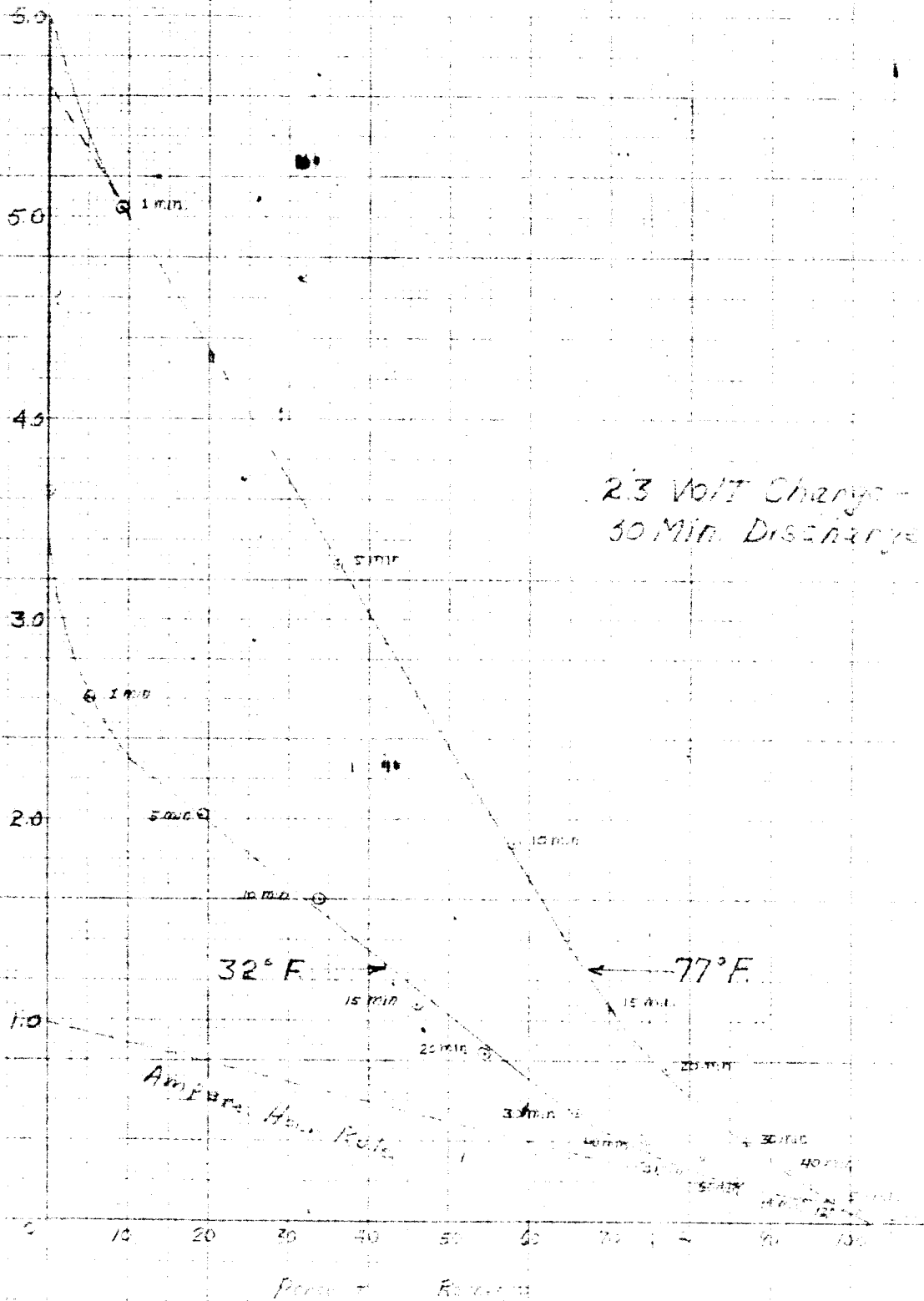


FIG. 4

Typical Cycle @ 32°F.
2.3 Volt Charge

Charge

Discharge

Current

Current

Voltage

Voltage

Amps

Amps

Volts

MINUTES

0 10 20 30 40 50 60 70 80 90 100 110 120

4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

FIG. 5

Typical Cycle @ 32°F.
2.4 Volt Charge

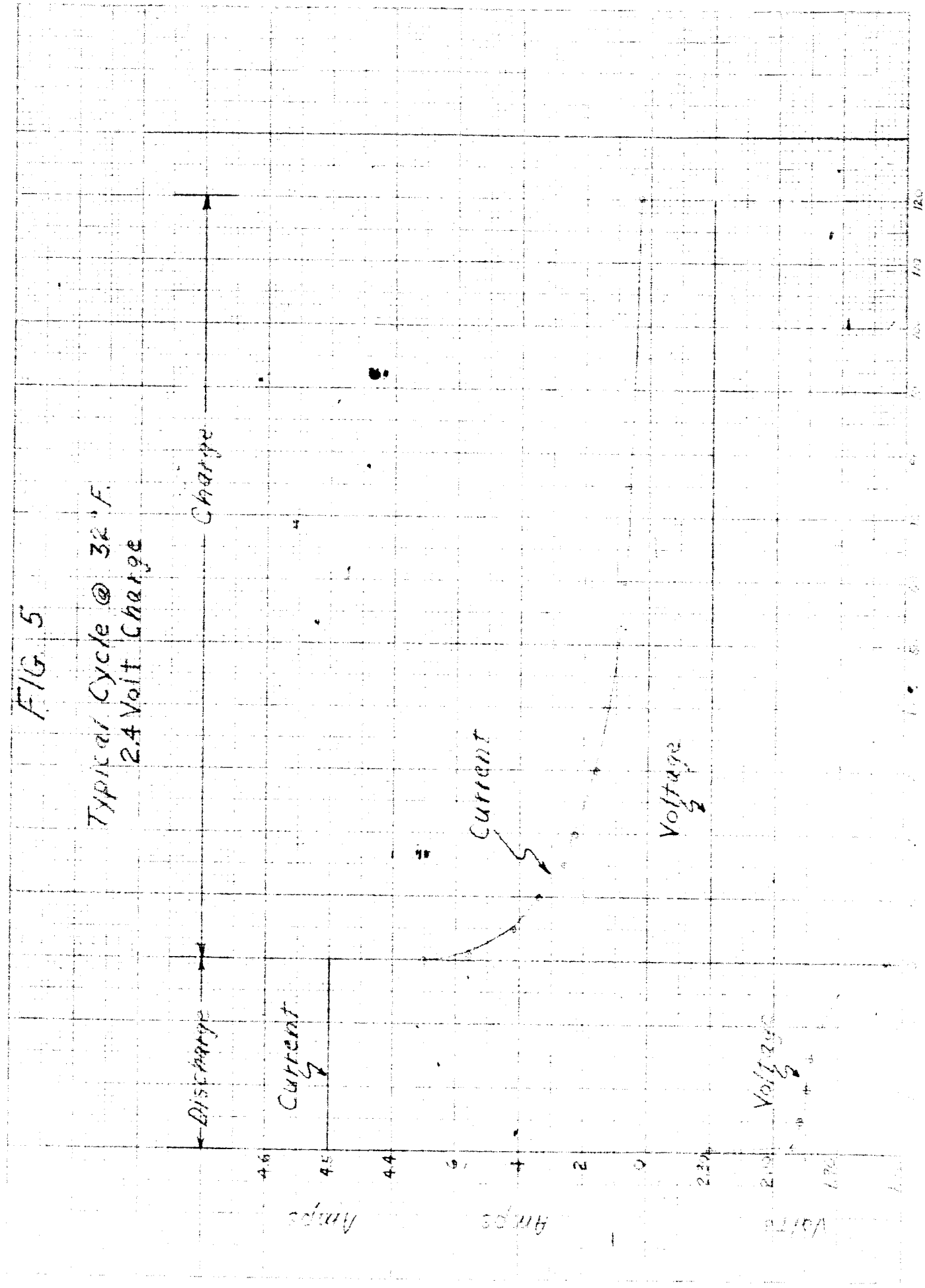
Discharge

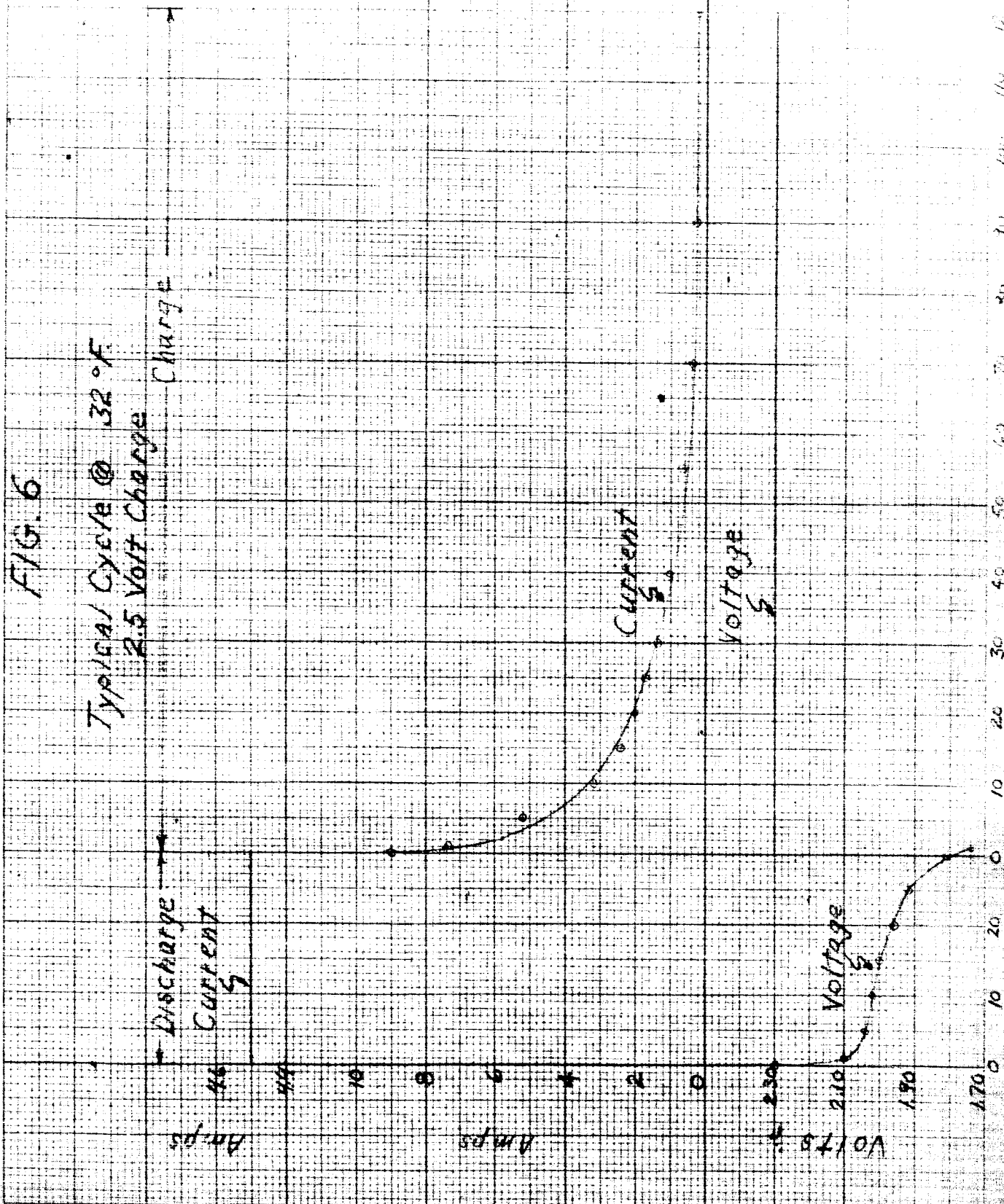
Current

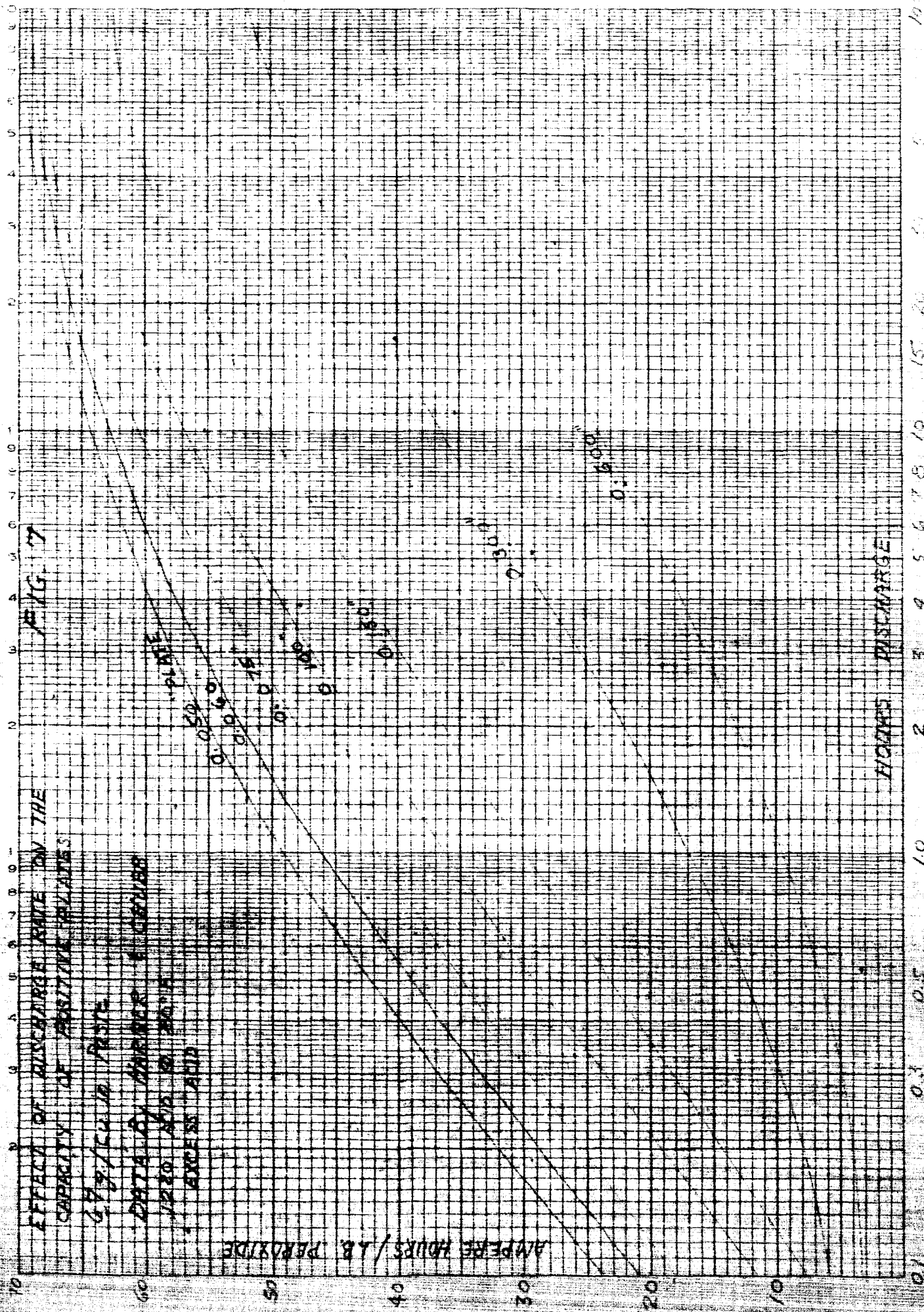
Current

Voltage

Voltage







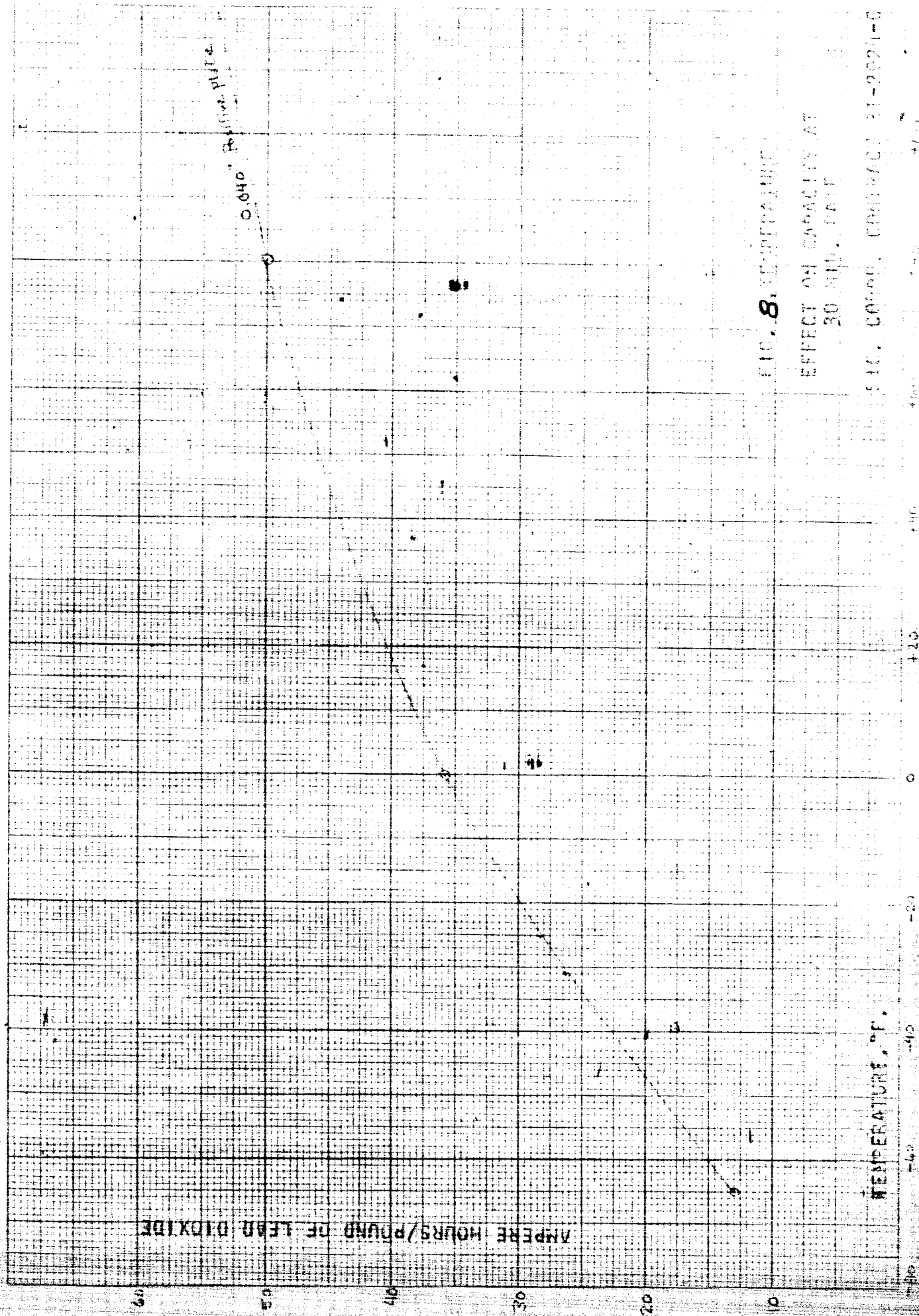
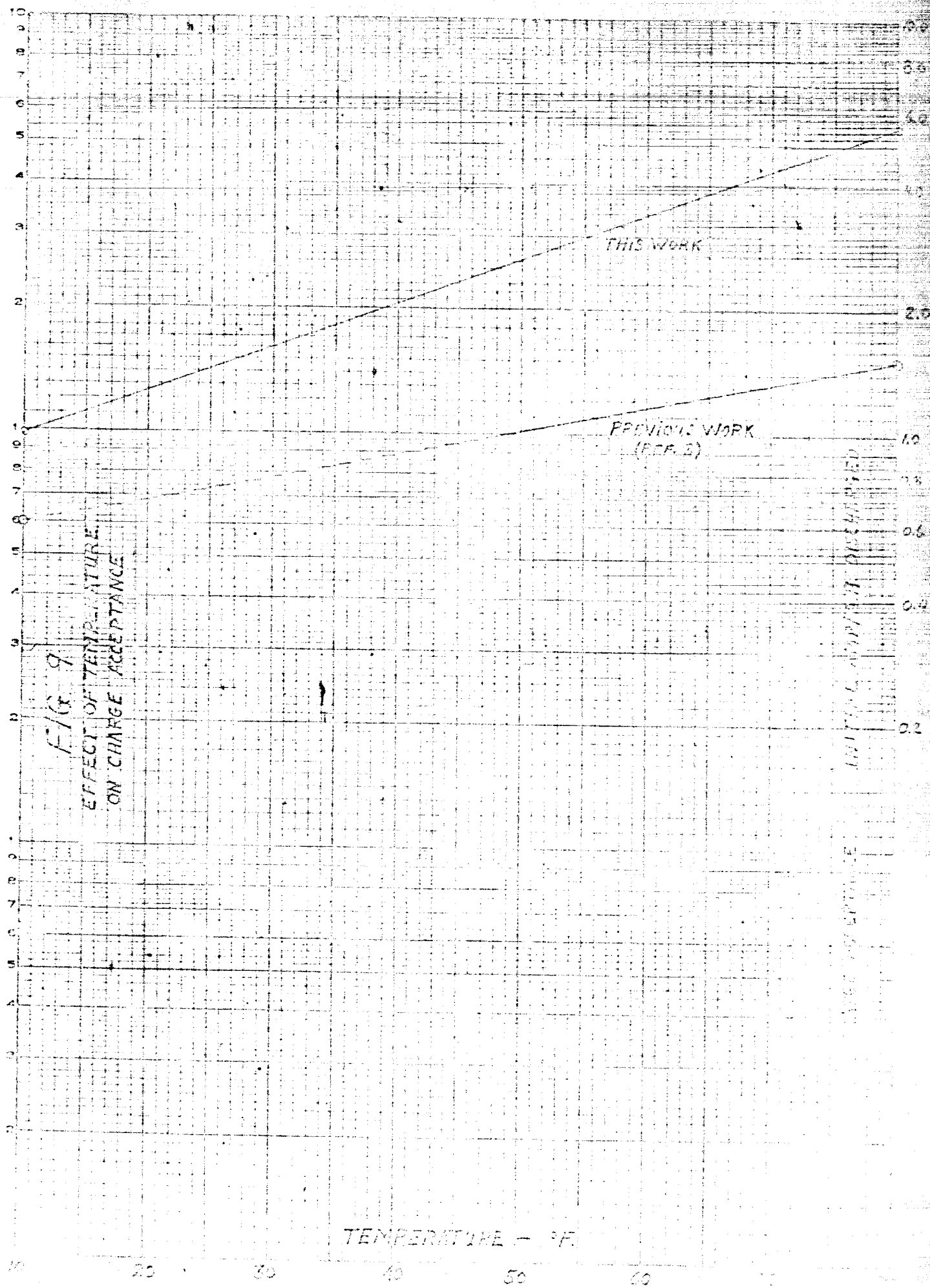


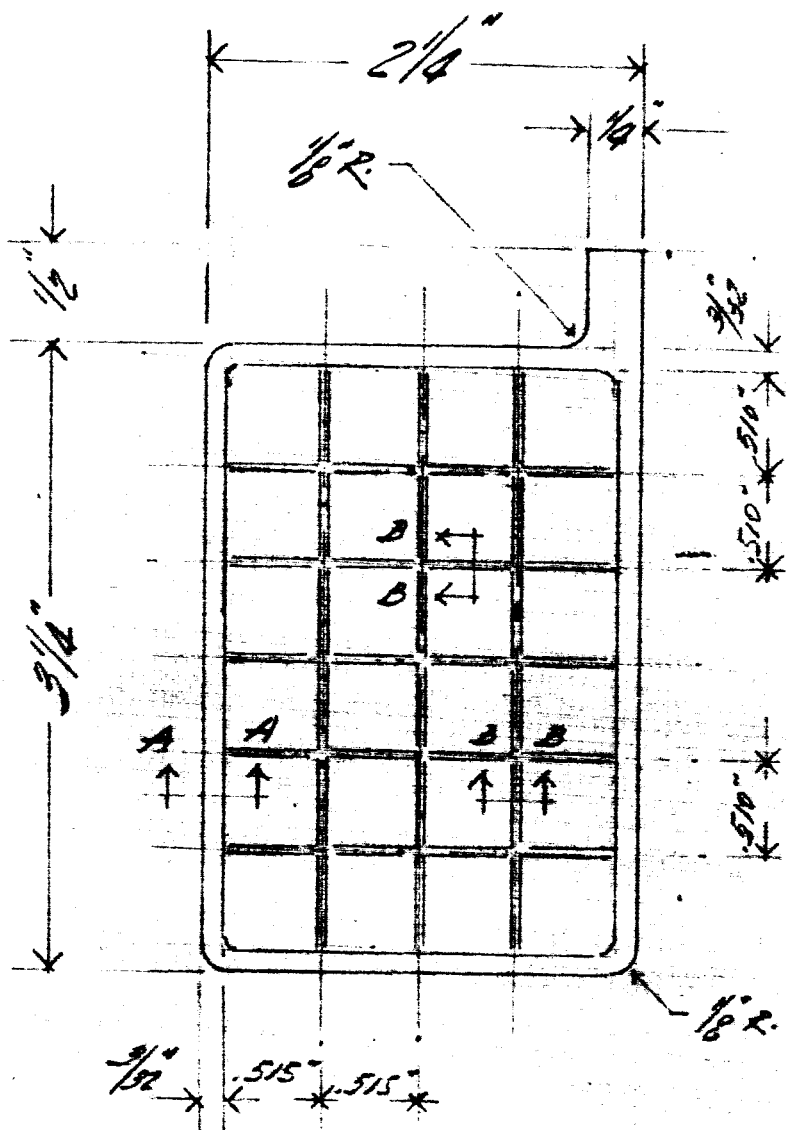
FIG. 8. TEMPERATURE

EFFECT OF CAPACITY AT
30 M.P.S. CAP

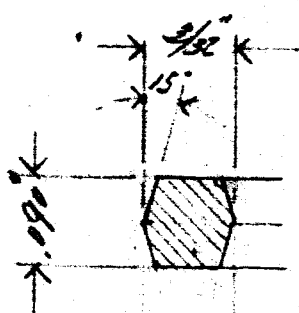
FIG. 10. CAPAC. CONDUC. 31-2021-0

TEMPERATURE, °F.

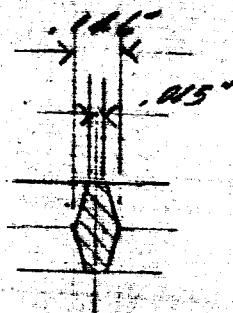




POSITIVE GRID



SECTION A-A

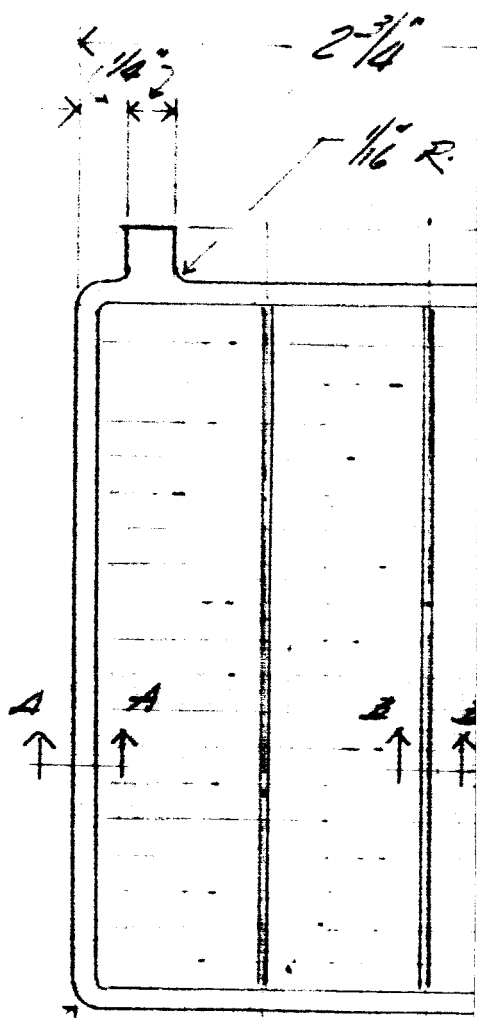


SECTION B-B

SCALE 5"=1"

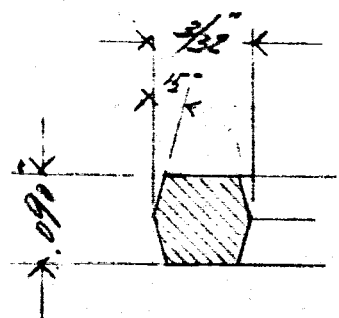
MATERIAL

CALCIUM



$\frac{1}{8}$ " R.

$\frac{1}{8}$ " R.



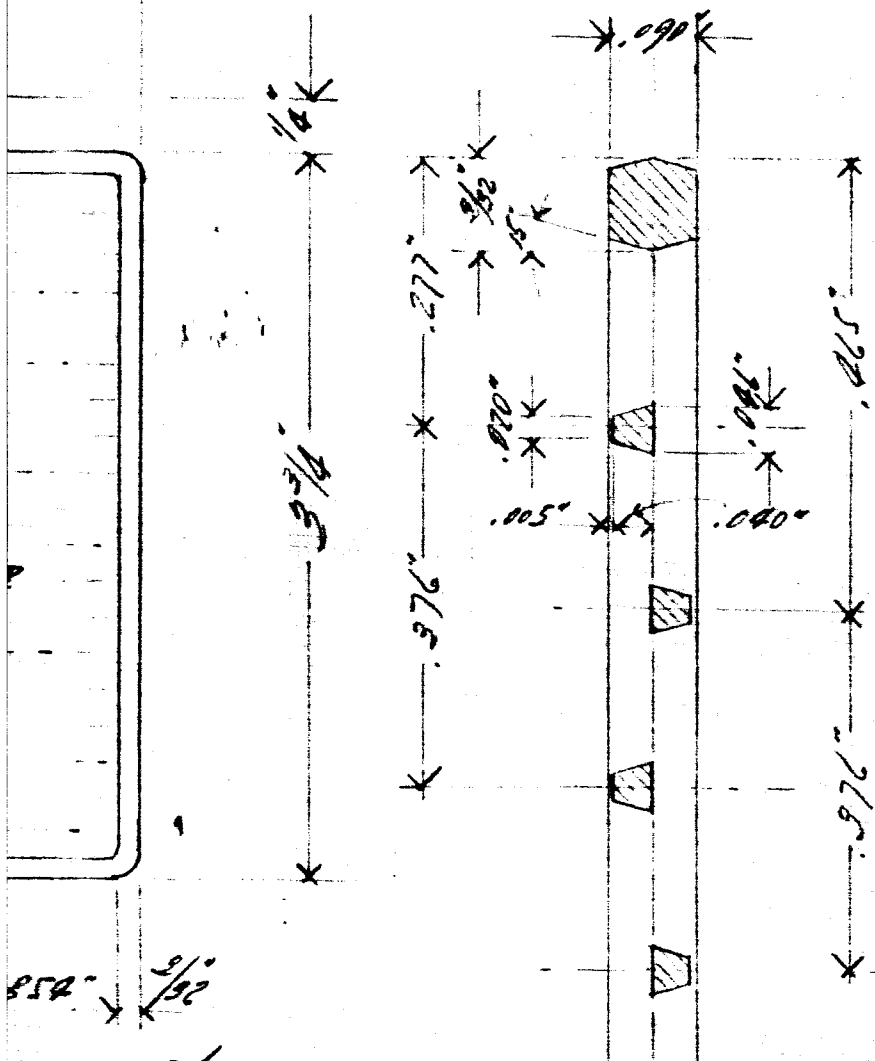
SECTION A-A

~

Scale 5"


MAR - 8 1966

OF PREVIOUS ISS.



NEGATIVE GRID

3

NO.	DATE	BY	REVISION
 E&S CD BATTERIES DIVISION OF ELTRA CORPORATION CONSHOHOCKEN, PENNA.			
<p><i>GRIDS FOR HERMETICALLY SEALED CELL</i></p>			
DRAWN <i>W. DRESCHER</i>		APPROVED <i>SPR...</i>	
CHECKED <i>...</i>		DRAWING NO.	
DATE <i>12-31-63</i>		<i>K-3197</i>	
SCALE <i>1:1</i>			

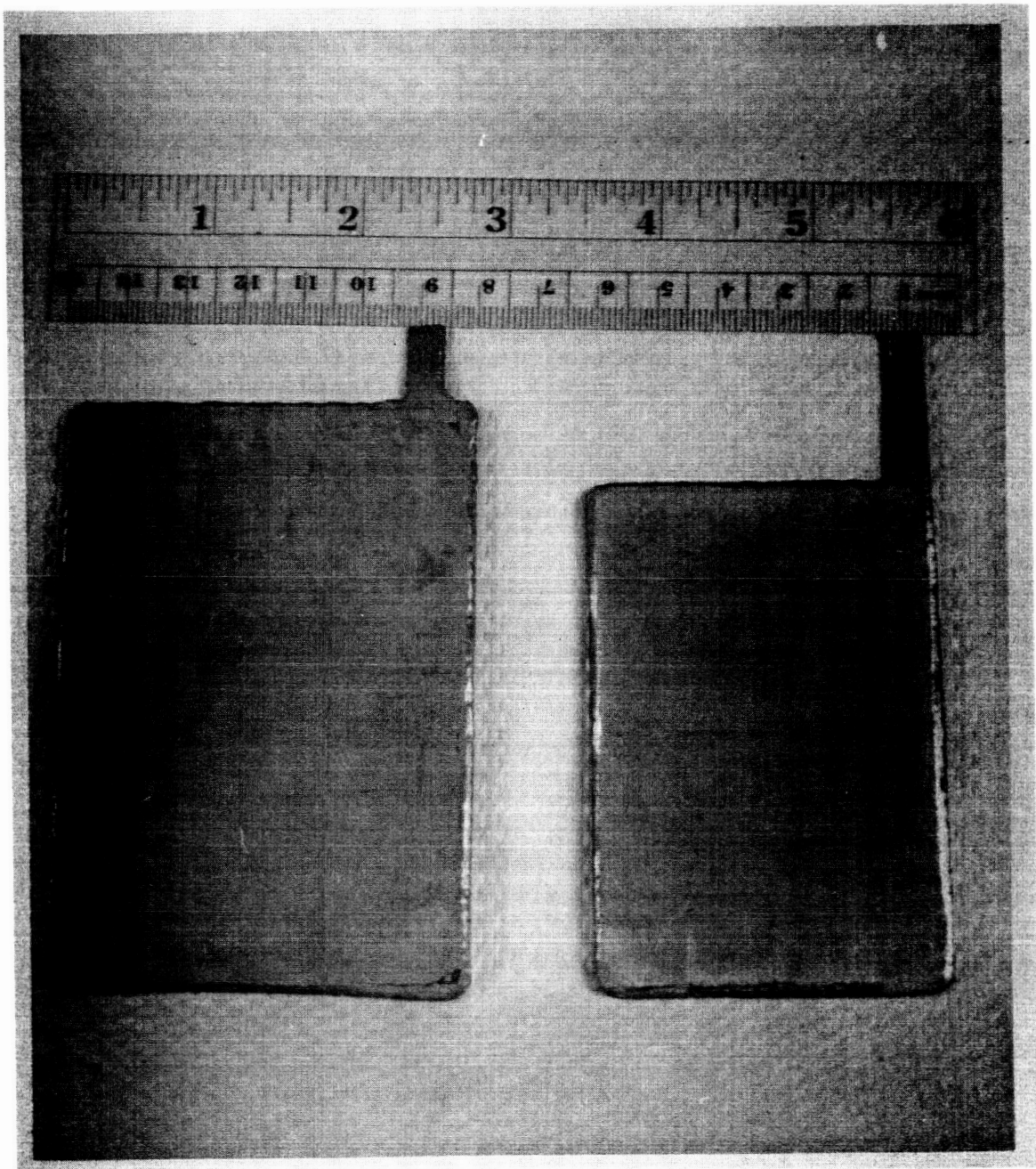


FIG. 11
NEGATIVE AND POSITIVE PLATES

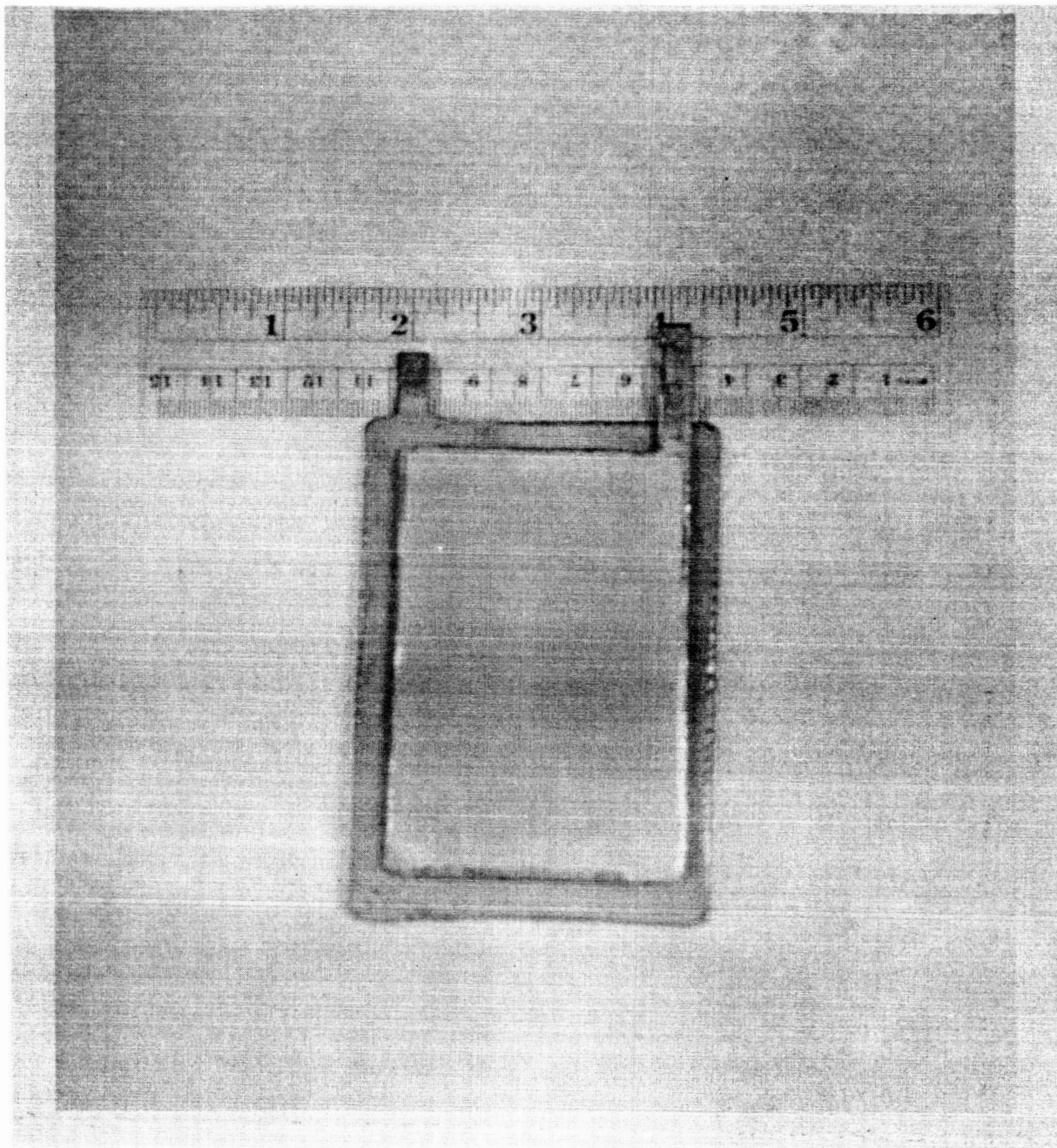


FIG. 12
POSITIVE PLATE IN POSITION ON NEGATIVE PLATE

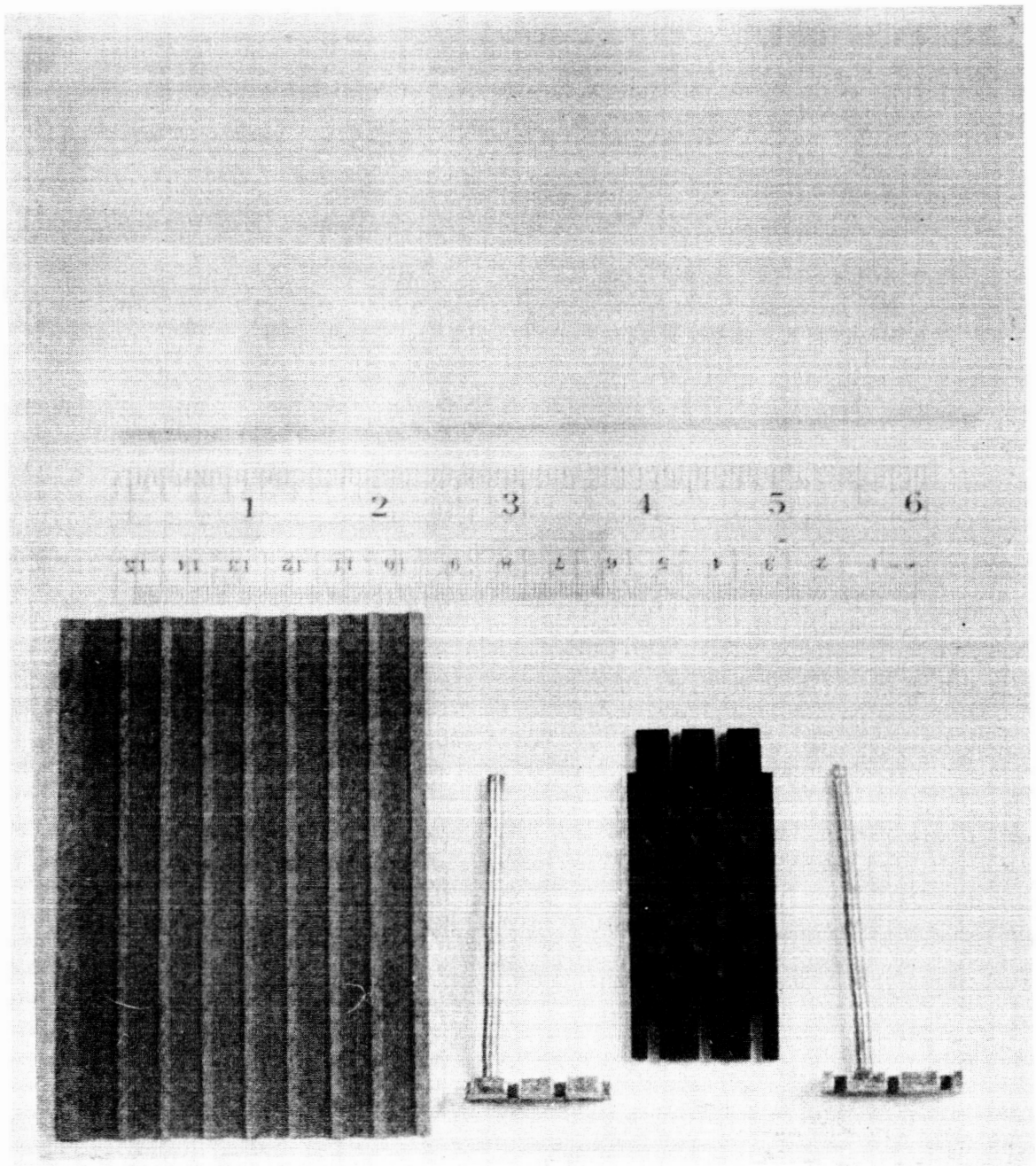


FIG. 13
SLYVER GLASS, SEPARATOR, MOSS SHIELD AND POSTS

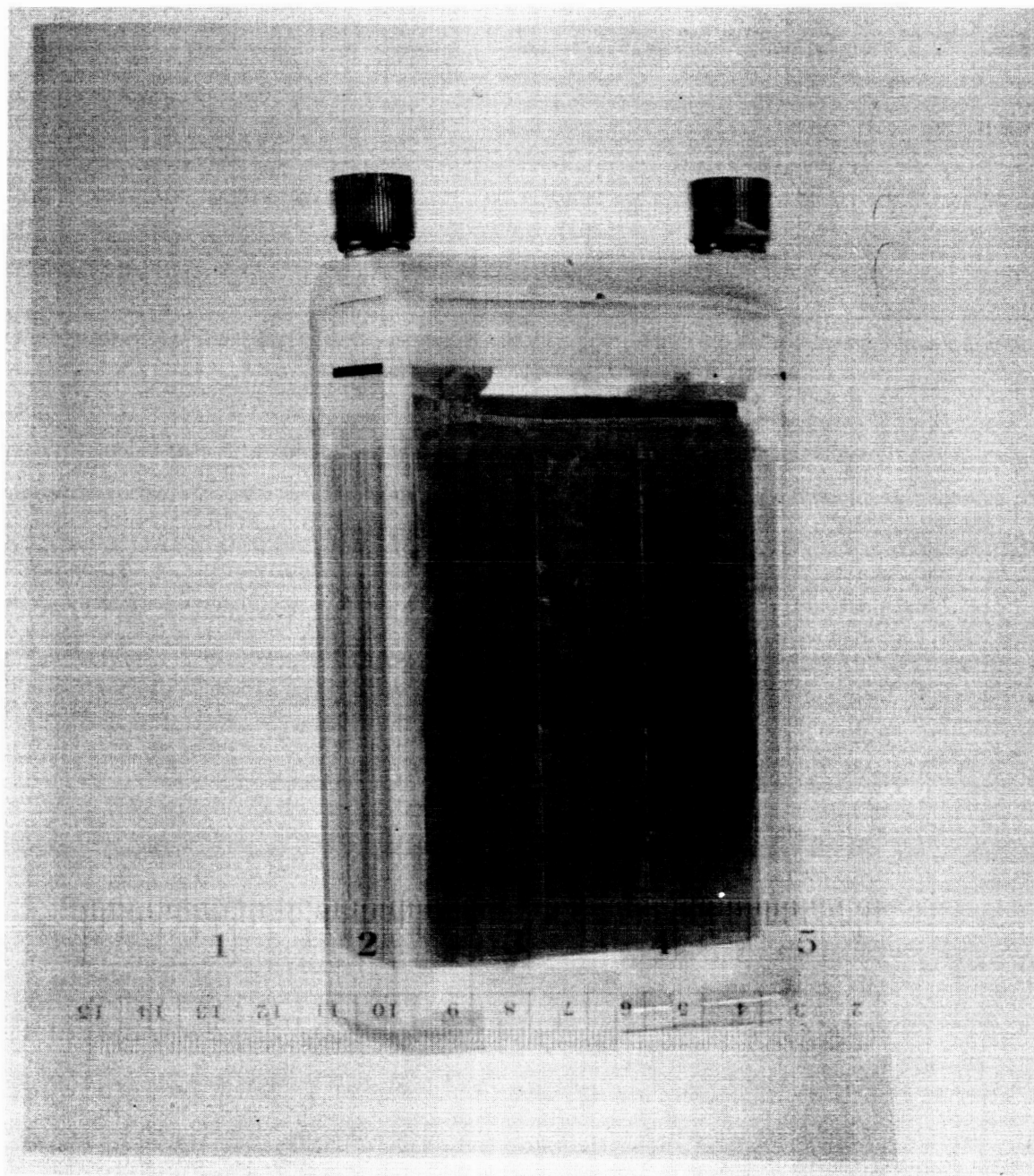


FIG. 14
SEALED CELL BEFORE COMPLETE ENCAPSULATION

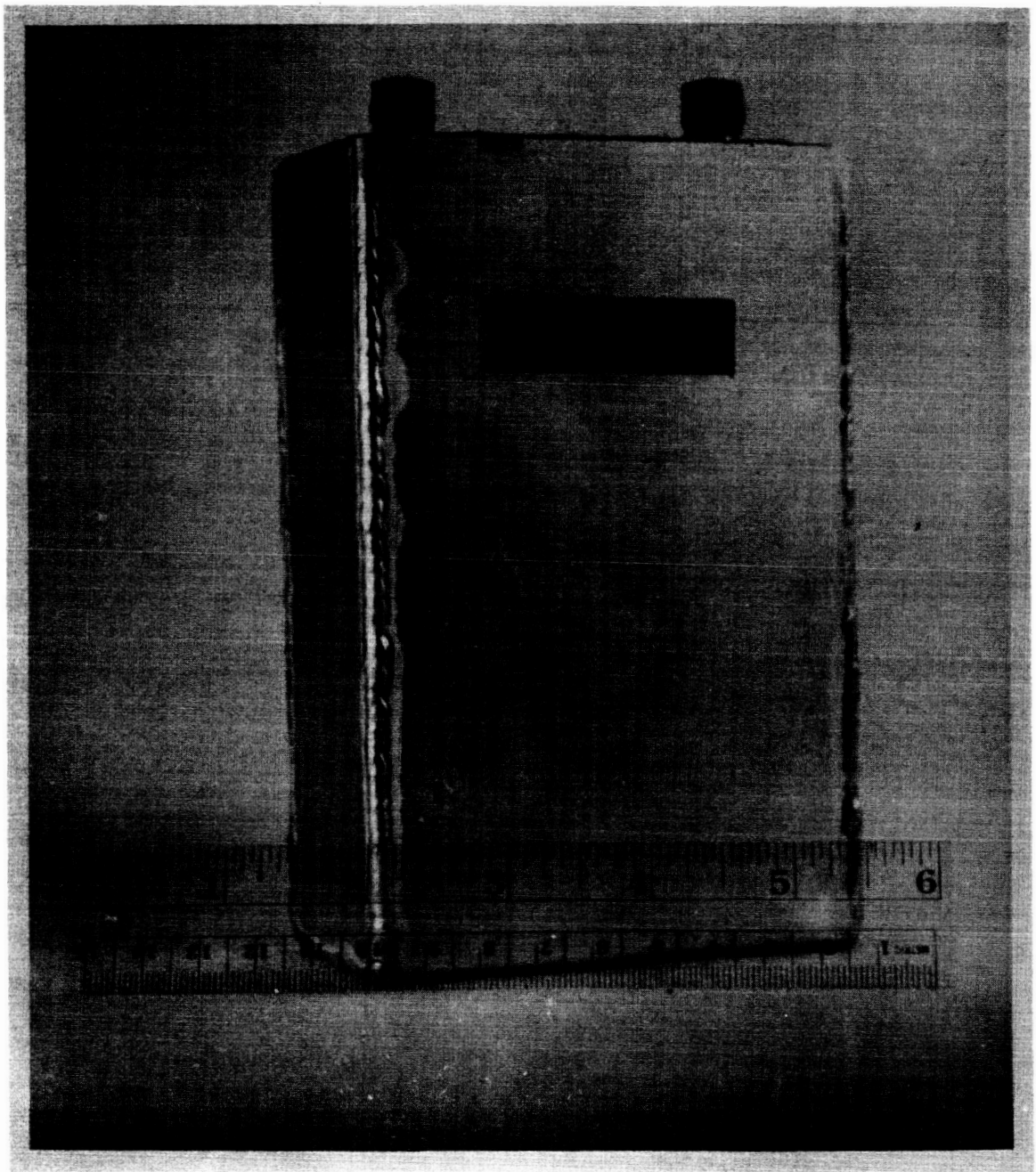
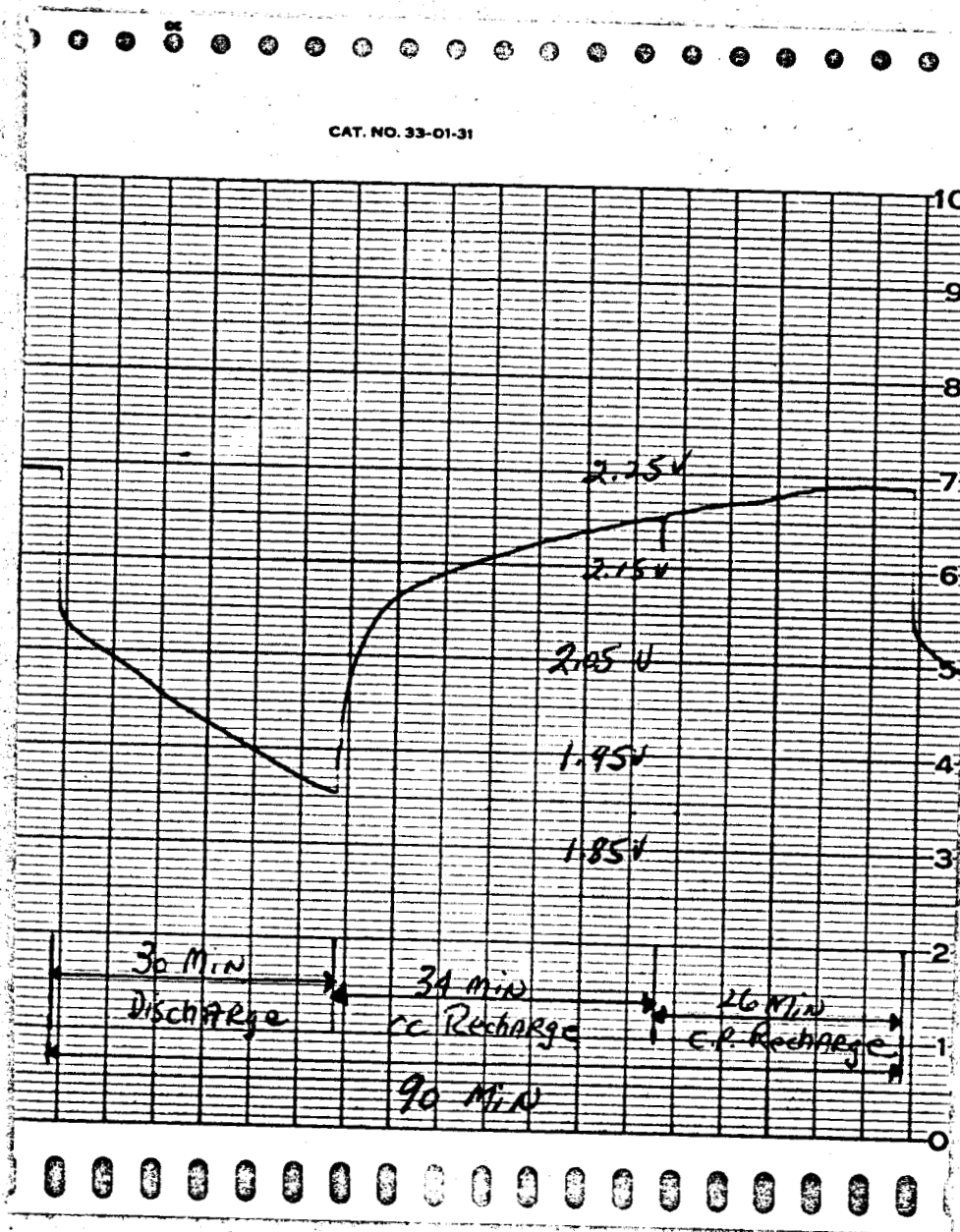


FIG. 15
SEALED CELL COMPLETELY ENCAPSULATED

20% Depth of Discharge (C/5)



Chart

This is a differential voltage recording of one cell in a battery of 5 cells during one cycle.

- Discharge Current - 2 amps.
- CC Recharge - 1.0 amps.
- CP Recharge - (current limited to 1.0A)

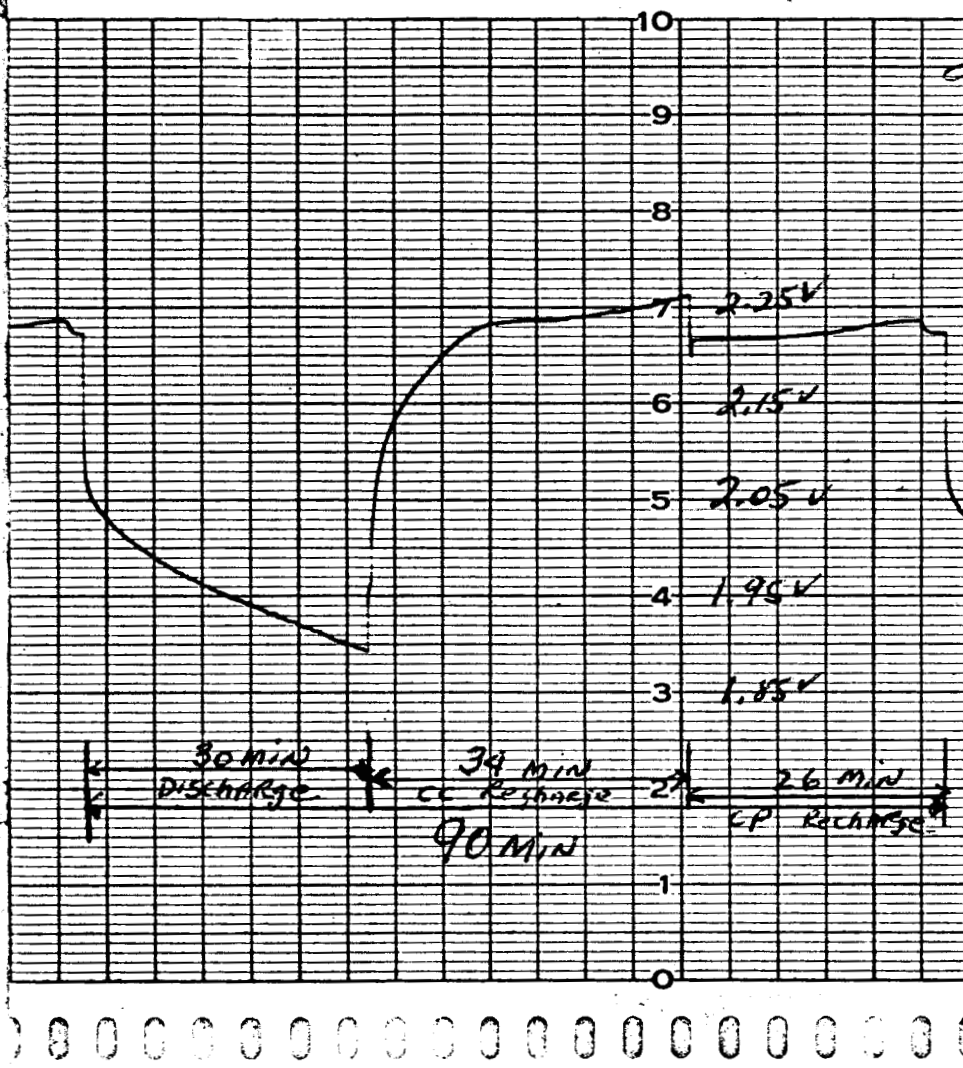
Number of Cycles before extended recharge - 125
(end of discharge voltage 1.75 volts/cell)

Temperature - 80° F.

Cell not sealed.

50% Depth of Discharge (C/2)

ME INCORPORATED ROCHESTER, N.Y.



This is a differential voltage recording of one cell in a battery of 5 cells during one cycle. The little dip in the C. P. recharge the last few minutes of charge indicates that a cell in the battery has increased in voltage to well above the gassing voltage.

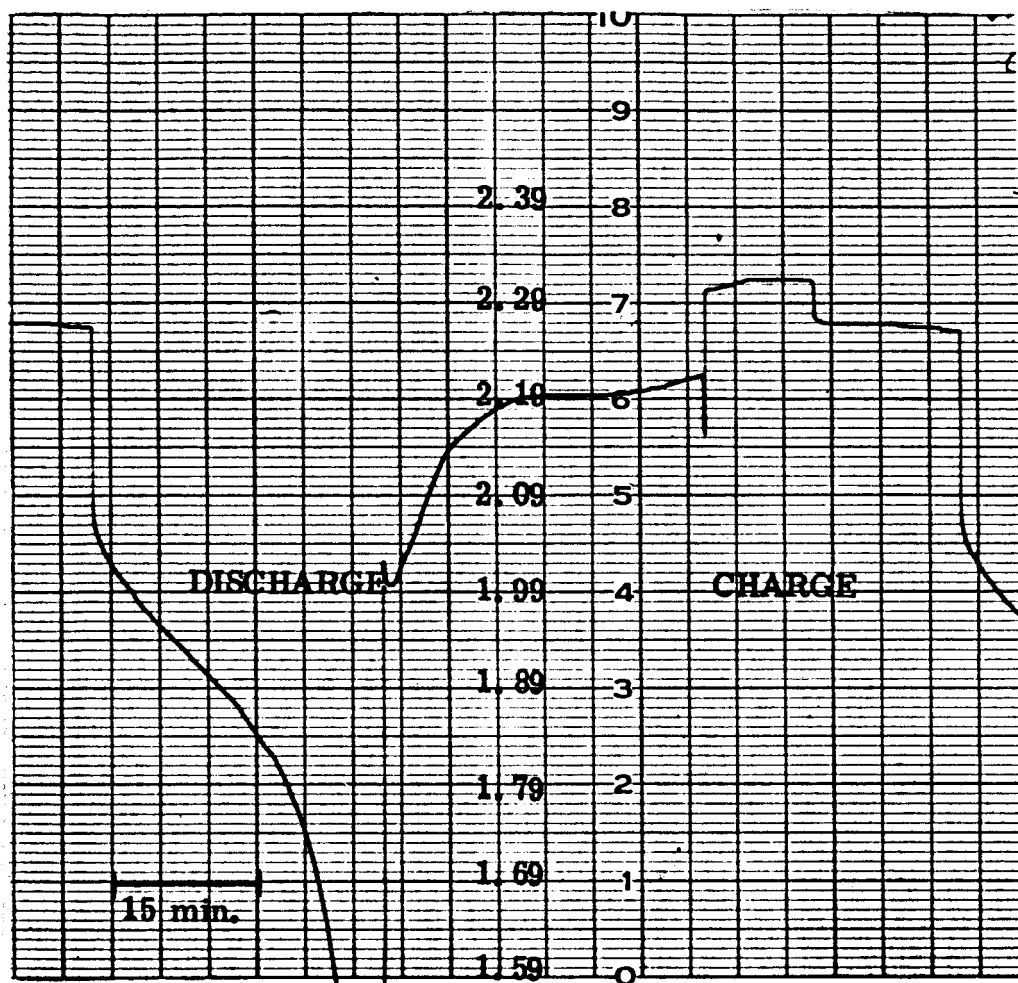
Discharge Current - 5 amps.
 CC Recharge - 3.2 amps
 CP Recharge - (current limited to .9 amp.)

Number of cycles before extended recharge - 30
 (end of discharge voltage 1.75 volts/cell)

Temperature - 80° F.

Cell not sealed.

Fig. 17



C/2 Discharge - 90 minute orbit

180 me gas in 16 cycles

C/4 Charge and CP 2.3 volts/cell

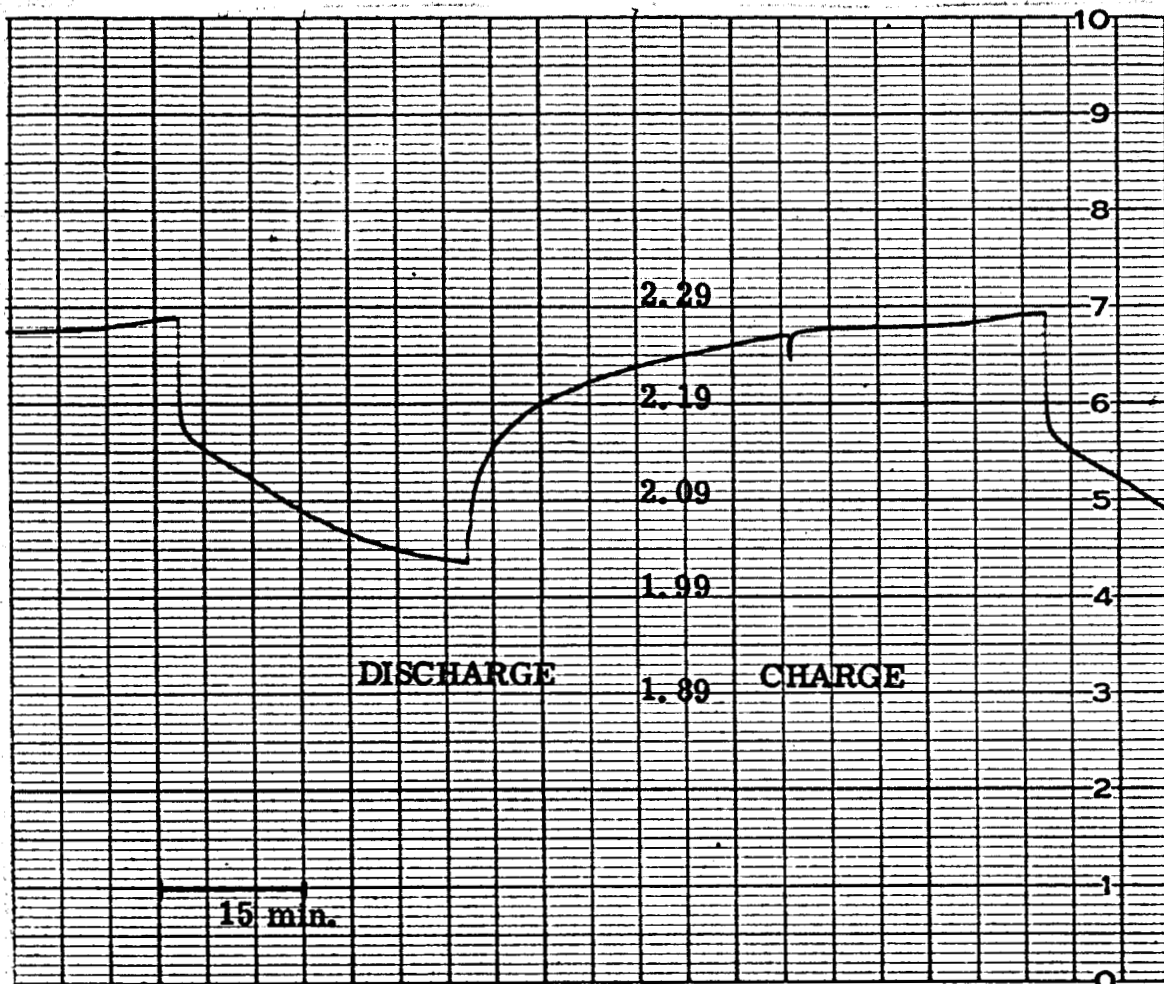
Discharge Current - 5 amps.

CC - 2.5

CP - 2.3 volts/cell

The humps in the constant potential part of curve are caused by other cells in the battery going to higher voltages.

Fig. 18



C/5 Discharge Rate
 Differential recording single cell in 5 cell battery (Series C).

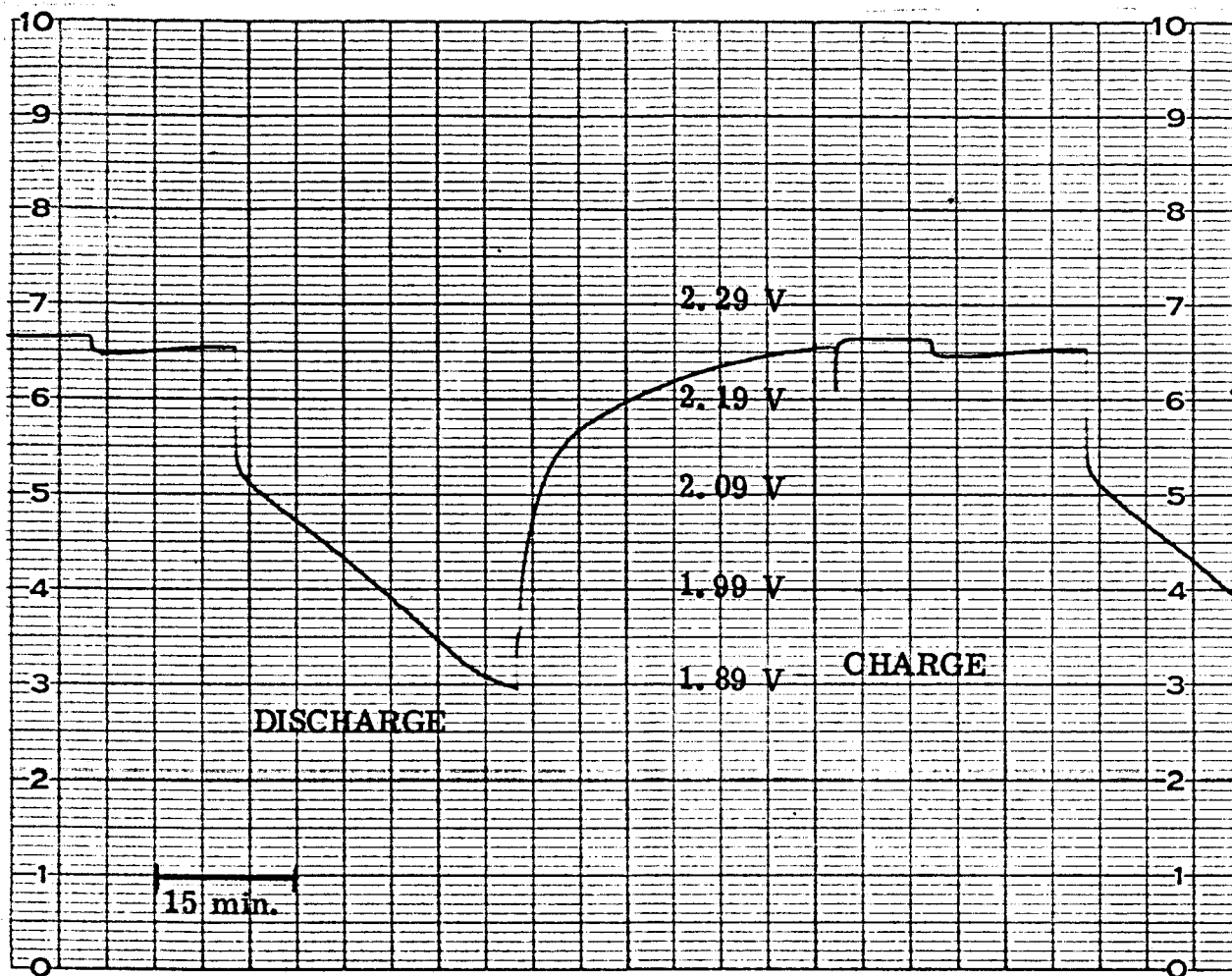
Discharge 2.0A/30 min.

CC 1.0A

CP 11.6 volt (2.32/cell)

Duty cycle at Cycle #97

Fig. 19



C/5 Discharge Rate

Discharge 2.0 A/30 min.

CC 1.0

Same as battery on previous curve at cycle 137

60 cc gas collected in the 40 cycles.

Fig. 20